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EFFECT OF ELECTRON INJECTED AIR ON THE THERMAL DECOMPOSITION OF SOLID WASTES (PART 2: ANALYTICAL INVESTIGATION)

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ABSTRACT

The main purpose of this study is to obtain clean and efficient thermal energy by producing a direct current electric field to the flame reaction zone and to provide the thermochemical transformation of biomass (wood) particles controlled by the process produced in the field. In this regard, a mathematical model for modeling the thermal decomposition in the presence of an electric field, as well as, an experimental work has been developed. The equations of aerothermochemistry are coupled to balance equations for densities of charged species, and a Poisson equation for electrical potential is solved. The results obtained show that the presence of the electric field significantly improves the stabilization of the flame. The electron injection affects the char combustion process significantly. The field enhancement the combustion characteristics, and the flame reaction zone of field induced ion wind on biomass thermal decomposition was analyzed.

Keywords: biomass, electron injected air, numerical model

1. INTRODUCTION

Pointed out for its contribution to atmospheric pollution and global warming, combustion remains an essential energy production method whether it is based on petroleum products, from biomass or waste. It is therefore essential to continue to develop techniques to optimize the efficiency and environmental impact of combustion energy systems.

The electric field control of combustion characteristics has always been a meaningful research topic, which has theoretical significance and practical application prospect to improve and stabilize the process of industrial burners, boilers, furnaces and engines [1-7]. According to the Navier-Stokes equation system, the main step of the change of combustion characteristics caused by electric field is the combination of the ion wind effect.

A large number of experiments have been carried out on different electrodes to optimize the electric field effects of AC and DC on the flame and combustion characteristics configured with a single electrode, as well as the sequence electrodes located in the combustion volume have been conducted [8, 9].

A new technology to assist combustion that is experiencing a real boom is the use of active control systems such as plasma or acoustic excitation. Indeed, for several years, many studies are conducted for the understanding and use of cold plasmas to assist combustion. Nevertheless, this field is still unknown and the mechanisms of reaction are not formally identified.

In the present research, the main objective is to develop a model to integrate the numerical simulation codes with the present experimental data, to describe the interaction between weak electric fields and combustion to better understand the mechanisms involved, as well as, to provide a code that predicts the response of flames to electric fields. Which will have great potential for understanding physical phenomena.

2. EXPERIMENTAL

The experiments were performed using a device named ERCM (Earth-Resource-Ceramic-Machine), where a modified fixed bed reactor was adopted to investigate effects of different parameters including electron injected air (ON/OFF) with a reaction temperature (350-500°C) of the decomposition degree (volume reduction rate) and the syngas generation characteristics during the ERCM process of cellulose. The bed dimensions are the height of 215 mm and the inner diameter of 15 mm. More details about present experiment is found in part 1.

Measurement devices of temperature, gas component (micro GC) for different species (H_2, O_2, N_2, CO, CO_2, CH_4, C_2H_4, C_2H_6). The negative ion (anion) used in this experiment was emitted from the negative ion generator ITM-F201 device, produced by Andes Electric Company Japan, whose specification is shown in Table 1.

Table 1. Anion Generator Specification

Anion Generator ITM-F201	
Power Consumption (Watt)	0.4
Method of Ion Production	Corona discharge type (inti-fion registered technology)
Anion Produced Rate	more than 500,000 ion per cc
Weight (gram)	30

3. CHEMI-IONIZATION KINETICS REACTION MODEL

3.1 Momentum Equation

$$\frac{\partial(\phi\rho_g u_g)}{\partial t} + \nabla(\phi\rho_g u_g u_g) = F_i - \phi\nabla P_g + \phi\rho_g g - \beta(u_g - u_s) + \nabla\phi\tau_g \quad (1)$$

When an electric field is applied, the component of the electric force applied to the charge carrier, F_i, is determined by the electric field intensity and the component of the charged material concentration n^+, n^- [6]:

$$F_i = eE_i(n^+ - n^-) \quad (2)$$

where the +ve and -ve subscripts denote properties of positive and negative ions, respectively. e is the electron charge. The electric field intensity is correlated with the potential V through a simple differential equation:

$$E_i = \frac{\partial V}{\partial x_i} \quad (3)$$

The Poisson equation describing the redistribution of electric potential, which must be solved at each time step, and the equation develops with the change of the concentration of charged matter as follows:

$$\nabla^2 V = -e\frac{(n^+ - n^-)}{\epsilon_0} \quad (4)$$

ϵ_0 represents the permittivity of free space.

3.2 Energy Equation

$$\frac{\partial((\phi)\rho_g c_{pg} T_g)}{\partial t} + \nabla(\phi\rho_g u_g c_{pg} T_g) = (\lambda_g.\nabla T_g) + A_s h'_s(T_g - T_s) + S_{T_g} - S_r + \pi D(\Theta - 1)q_w + f \quad (5)$$

S_r is the volumetric net radiation losses.

The thermal contribution from the generator is defined as the difference between the electric power P_1 and the heat losses into the reactor wall P_2.

$$(P_1 - P_2)/V = \xi q_{arc} \quad (6)$$

Here q_{arc} is a power distributed into a reactor volume Sdx and $\xi = (1 - P_2/P_1)$ is the thermal efficiency of the plasma reactor. The arc electric power is expressed in terms of the heat loss to the wall

$$P_2 = \pi D \int_0^{L_R} q_w(x)dx \quad (7)$$

The electric force contribution in total energy transport equation is given by [10]:

$$f = \sum_{k=1}^{N_c} en^k S^k E_j(u_j + V_j^k) \quad (8)$$

With N_c the number of charged species and n^k the concentration in part/m^3.

3.3 Species Equation

$$\frac{\partial(\phi\rho_g Y_{ig})}{\partial t} + \nabla(\phi\rho_g u_g Y_{ig}) = \nabla\left(D\ \nabla(\phi\rho_g Y_{ig})\right) + S^k\rho\mu^k Y^k E_j + \dot{\omega}^k \quad (9)$$

k is representing a neutral species, an ion or an electron. The diffusion coefficient of the ions is approximated by the diffusion coefficient D of the corresponding neutrals [11]:

$$D^k = D = \frac{\mu}{\rho Sc} \quad (10)$$

For a very weakly ionized media such as flames, the electron diffusion coefficient is approximated by Delcroix [12]:

$$D^e = \left(\frac{m^i}{m^e}\right)^{0.5} D^i \quad (11)$$

m^e represents the electron mass and m^i is the averaged mass of ions.

3.4 Numerical Scheme

All the transport equations are discretized in space using a finite volume method and discretized in time using backward Euler. The PISO algorithm is used for the bulk flow along with a 2nd order gradient-limited space discretization for the convective terms. The equations for the ions in contrast discretize the convective terms using a 1st order upwind method for the combined drift and bulk velocity. The Initial bed material was solid residue processed and discharged from the pilot-scale ERCM facility, and it is known that this residue has a property of emitting electrons. Furthermore, it is also known that heating of this residue emits more electrons [13].

4. MODEL VALIDATION

Fig. 1 illustrates the comparison between the numerical model and the present experimental results for the CO_2 concentration at different reaction temperatures for the electron ON and OFF cases. The results obtained by this model show a good agreement with the experimental results.

5. RESULTS AND DISCUSSION

The physical strength induced by electric field enhances the heat and mass transfer of flame matter in the field direction (ion wind effects), and the field induced Lorentz force boosts up the flow vorticity with the enhanced air-fuel mixture.

The results of this study confirmed that the thermal decomposition of biomass was enhanced by injecting electrons into air on the basis of flame, accompanied by the formation of volatile matter (H_2, CO) enhanced during the primary combustion stage.

The enhanced thermal decomposition of biomass is followed by enhanced ignition and combustion of volatile matter, which determines the formation of the main product CO_2 (Fig. 2) and the negative correlation of ion current.

H_2, CO, and CH_4 (Fig. 2) was significantly released at the beginning stage of the reaction. While, CO_2 (Fig. 4) gradually increased to some extent from the middle stage of the reaction. From these results, it can be concluded that the thermal decomposition reaction occurred mainly at the beginning stage, and the combustion reaction occurred in or after the middle stage.

From the release behavior of H_2 and CH_4, we can say that the electron injection may not affect the pyrolysis process significantly. Moreover, from the release behavior of CO and CO_2, it is noted that the electron injection would affect the char combustion process significantly.

The electric field induced variations of the main flame characteristics at the combustion of biomass. First of all depend on the formation of charged flame species, i.e. negative ions. Therefore, to provide the effective electric control of the main flame characteristics, it is necessary to apply the electric field to the flame area with a maximum of the ion concentration.

This suggests that the ion formation at the thermal decomposition of biomass is a consequence of the release of different traces of hydrocarbons. The analysis of the produced gases released at the thermal decomposition of biomass confirms an intensive formation of the combustible volatiles (H_2, CO) and hydrocarbon traces (CH_4), which are responsible for the formation of the flame reaction zone and primary flame ions. Hence, to obtain the most intensive field-induced variations of the flame characteristics, the electric field must be applied to this part of the flame.

6. CONCLUSION

The effect of electric field on the thermal decomposition of biomass improves the temperature homogenization, promotes the release of the main pyrolysis products (CO and CH_4) and increases the heat energy consumption. The mechanism of thermal decomposition of biomass caused by DC electric field is considered to be the overlap of "ion-wind" effect caused by field, which enhances the homogenization and stabilization of temperature and the field-induced interfacial polarization of biomass caused by field.

The numerical results show that the effect of the electric field on the combustion is the reason why the field intensity enhances the ion wind movement, which by default enhancement the heat and mass transfer of biomass particles in the field and promotes the heating of biomass. Enhancing the formation of biomass thermal decomposition and volatile flow (CO, H_2).

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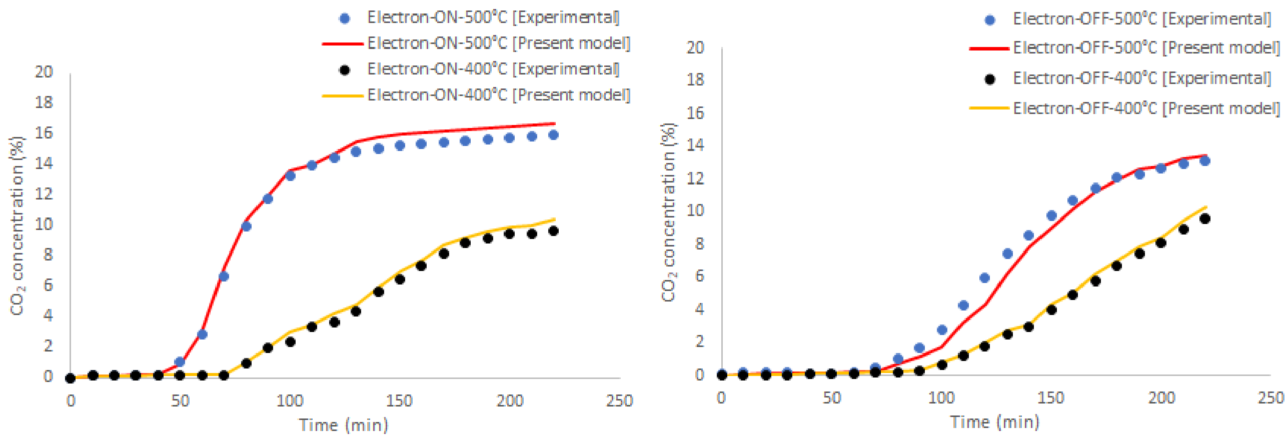

Fig. 3 Comparison between numerical and experimental results for CO_2 concentration at different reaction temperature for the electron ON and OFF cases

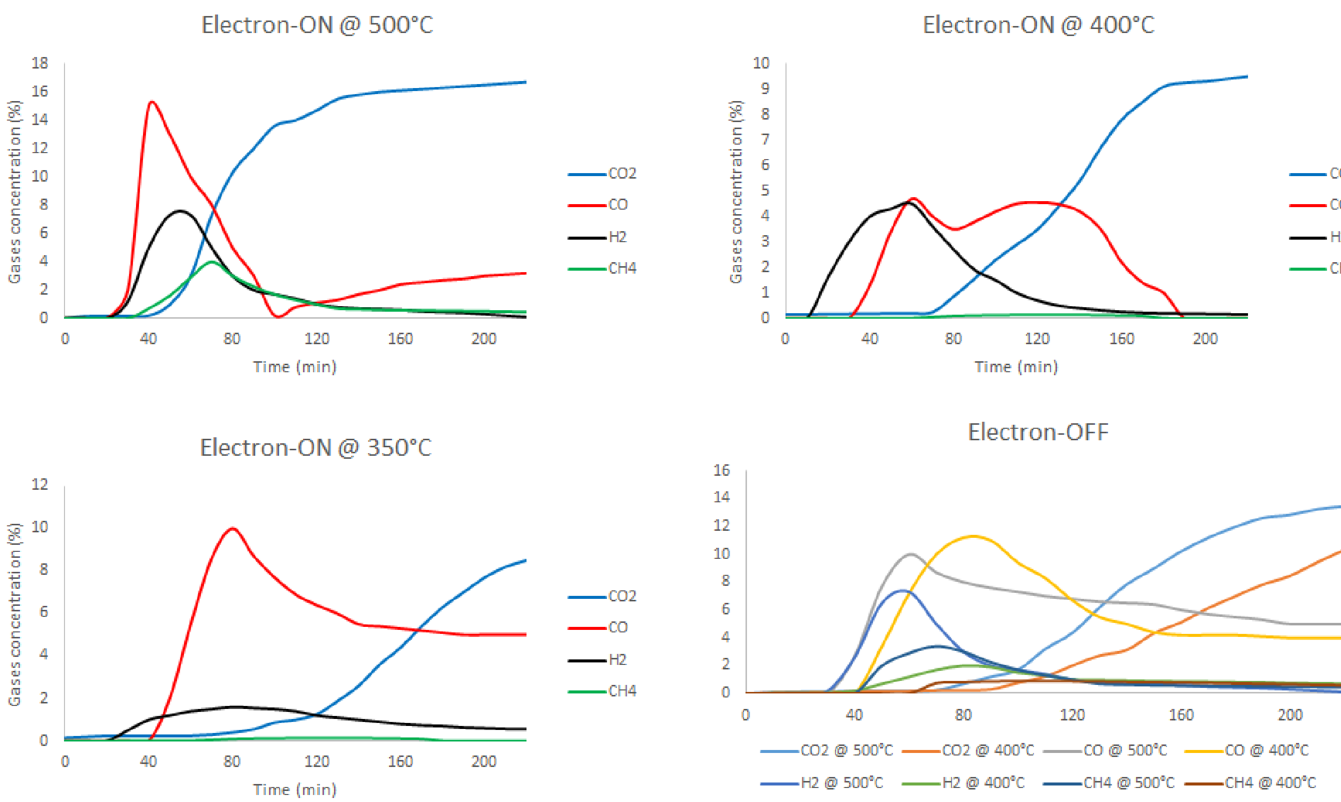

Fig.4 Numerical results of gases concentration (%) at different reaction temperature for the electron ON and OFF cases

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